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Longitudinal Analysis of Transit's Land Use Multiplier in Portland (OR)

Reid Ewing and Shima Hamidi

Problem, research strategy, and findings: We assess the direct and indirect effects on car use (as measured by household vehicle miles traveled [VMT]) of the Portland Westside Max light rail transit (LRT) extension. We use longitudinal data to estimate the effects of discrete changes in the built environment by comparing a treated transit corridor with a highway corridor that serves as a control. Before the LRT line, the transit and highway corridors were comparable in almost all respects, including household VMT. After the LRT line was completed, the transit corridor had higher density, generated significantly more household walk and transit trips, and experienced a slower rise in VMT per household. We estimate a transit multiplier of 3.04, meaning that transit reduces VMT by three vehicle miles in total for every vehicle mile reduced due to transit ridership. The direct effect occurs through increases in transit ridership and associated reductions in household VMT. The indirect effect is achieved primarily through increased walking around stations and secondarily through increased densities around stations. Fixed-guideway transit in tandem with comprehensive public policies that promote transit-oriented development (TOD) around transit stations on one hand, and highway corridors on the other, produce different transportation outcomes.

Takeaway for practice: Building rail lines with supportive local government land use policies and local and even state investments around rail stations can slow the growth of auto use.

Keywords: TOD, Portland, quasi-experiment, natural experiment, transit multiplier

Historically, research examining the role of public transit in reducing vehicle miles traveled (VMT) and greenhouse gas (GHG) emissions has focused directly on mode shifts from driving to transit occurring as a result of transit investments. Such research typically shows only modest reductions in vehicle travel (Arrington & Cervero, 2008; Bento, Cropper, Mobarak, & Vinha, 2005; Bhattacharjee & Goetz, 2012; Cervero, 1994; Litman, 2005; Renne, 2005; Vance & Hedel, 2007; Zegras, 2010). However, a growing body of research suggests that cities with comprehensive transit facilities and supportive public policies realize lower VMT that is not fully explained by mode shifts from driving to transit (Bailey, Mokhtarian, & Little, 2008; Holtzclaw, 2000; Lem, Chami, & Tucker, 2013; Los Angeles Metropolitan Transportation Authority, 2012; Neff, 1996; New York Metropolitan Transportation Authority [MTA], 2009; Newman & Kenworthy, 1999; Pushkarev & Zupan, 1982); that is, public transit investments have a multiplier effect often expressed as the number of VMT reduced per passenger mile of transit.

The multiplier recognizes that the long-term influences of transit—including more compact and mixed land uses in station areas, a higher propensity by users to chain trips, and a significantly higher rate of related non-motorized travel (walk and bike trips)—converge to reduce automobile travel to a greater degree than simply the distance traveled via transit. Even those who live near transit but do not use it may drive less because of the compact, mixed-use neighborhoods and opportunities to walk and bike fostered by transit and supportive public policies.

The literature on the transit multiplier has many gaps, most notably the absence of longitudinal studies that allow researchers to draw stronger causal

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inferences between transit expansion and VMT reduction than possible in correlational studies. This study seeks to fill that gap in the literature by assessing the effects of the Westside Max light rail transit (LRT) line running from downtown Portland (OR) to the suburban communities of Beaverton and Hillsboro. Using a quasi-experimental design, we compare household travel characteristics before and after construction of the transit line. The line was expected to—and did—affect development patterns and travel behavior of households proximate to it. In this natural experiment, the "treatment" is the construction of LRT. The "treated" corridor consists of station areas on the LRT line. The "control" corridor consists of equal areas around intersections on a highway corridor heading southwest from downtown Portland to Tigard, another suburban community. The two corridors are similarly situated within the region and had similar sociodemographics, densities, and household travel characteristics in 1994, four years before the LRT line was built. We find that, compared with the control corridor, the treated corridor not only generated more household transit trips, but generated more household walk trips, became denser, and saw a slower rise in VMT per household after LRT had been in operation for 13 years, a time span long enough to allow land use effects to manifest themselves.

This result is not unexpected, given our conceptual framework as shown in Figure 1. The provision of LRT leads directly to increased transit use, but equally important, acts in tandem with public policies to promote transit-oriented development (TOD) around transit stations. TOD, in turn, results not only in more transit trips but more walk trips. The public policies, in the case of the Portland LRT line, are manifold: Local governments have rezoned land around transit stations to permit TOD,

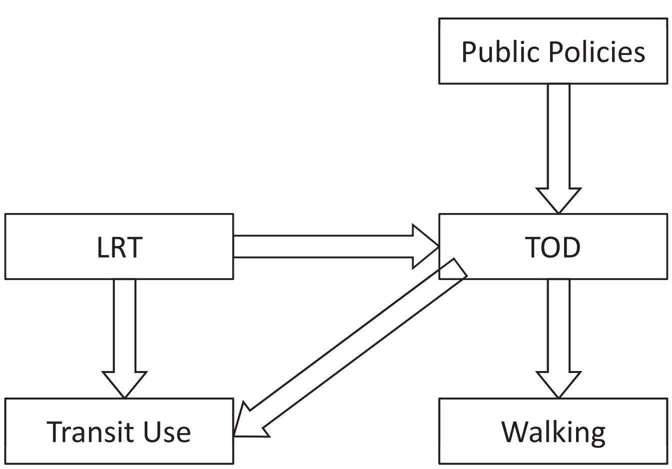

Figure 1. Conceptual framework by which LRT affects travel outcomes.

and have put public dollars into public and private projects around stations; the regional government, Portland Metro, has used public education and transportation investments to encourage TOD around stations; TriMet, the transit operator, has developed its own properties at stations; and the State of Oregon has provided tax incentives for development in designated centers and corridors, including around transit stations.

Understanding the Transit Multiplier

The transit multiplier is the ratio of the total VMT reduction associated with transit, including both direct and indirect effects on VMT, divided by the VMT reduction associated with transit use alone. The mechanism by which transit leverages larger reductions in VMT, and produces a multiplier effect, is straightforward. Transit creates opportunities for TOD around transit stations, "compact, mixed-use development near transit facilities with high-quality walking environments" (Cervero, Murphy, Ferrell, Goguts, & Tsai, 2004, p. 11). TOD may reduce per capita VMT independent of transit usage, as residents walk and bike more and make shorter automobile trips in a mixed-use environment.

However, researchers have yet to reach a consensus on the magnitude of the multiplier effect. Table 1 summarizes these studies, which draw on data from different cities and use different methods, and have produced estimates for the multiplier ranging from 1.29 to 9. Estimates of the multiplier can even vary widely within a given study.

Newman and Kenworthy (1999) calculate that for every one mile traveled on public transit, there is a displacement of 3 to 4.5 VMT in the United States and 5 to 7 VMT in other countries. They propose four reasons for VMT reductions due to the transit multiplier: 1) transit concentrates population and employment, which reduces trip lengths; 2) transit increases "trip chaining," as transit users combine multiple errands into a single public transit trip; 3) transit results in car shedding, as households with good access to transit service own fewer cars than their counterparts in unserved areas; and 4) transit, and the compact land use patterns it produces, increase walking and biking.

Holtzclaw (2000) estimates that, in San Francisco, every one passenger mile traveled on public transit displaced 9 VMT by car, while in two other California cities, Walnut Creek and San Ramon, transit displaced only 1.42 VMT. He attributes the difference in the multiplier to differences in population density; the population density in San Francisco is significantly higher than the other two cities.

Table 1. Summary of multiplier studies.

Study	Cities	Land use multiplier	Methodological issues
Pushkarev & Zupan (1982)	U.S. metro areas with at least 2 million population	4	Correlation only; does not show causal relationship of transit.
Newman & Kenworthy (1999)	32 global cities	5–7	Correlation only; does not show causal relationship of transit.
Holtzclaw (2000)	Matched pairs in the San Francisco Bay Area	1.4–9	Correlation only; does not show causal relationship of transit.
Neff (1996)	U.S. urbanized areas	5.4–7.5	Assumes fixed travel time budgets.
Bailey et al. (2008)	Entire U.S.	1.9	Accounts only for land-use effects caused by transit. The structural equations modeling used had relatively low explanatory power; may not be applicable to sub-national scales.
New York MTA (2009)	MTA service territory	1.29–6.34	Wide variation in results depending upon parameters selected.
Los Angeles Metro (2012)	Los Angeles County	5.3	Time series regression showed no effect; regional analysis comparing counties in greater LA produced the indicated multiplier.

Source: Data from American Public Transit Association (2009).

Bailey et al. (2008) conducted a national study based on data from the 2001 National Household Travel Survey. Using structural equation modeling, they find that each mile traveled on U.S. public transportation reduced VMT by 1.9 miles. They also find a significant correlation between public transit availability and reduced automobile travel, independent of transit use.

While the work to date on the multiplier effect has made important progress in exploring a complex phenomenon, there are several outstanding issues that make it difficult for transportation planners to apply the research summarized in Table 1:

- Widely varying estimates undermine confidence in the results of these studies and make it difficult to select a value from within the range of estimates. Usually in these cases, researchers can compare values or explain differences between studies due to samples, methods, and definitions, but in the case of the multiplier effect, the range of estimates is so wide that this has proven difficult.
- Results are difficult to generalize and apply to smaller metropolitan areas or areas that do not currently have extensive transit coverage. Most of the studies summarized in Table 1 draw data from the most populous metropolitan areas in the United States and, in one case, Europe; moreover, several of these studies are more than a decade old.
- It is difficult to separate cause and effect in many studies to date. Station areas may be compact because of transit or transit lines may be planned through such areas to maximize ridership.
- Assumptions are counterintuitive in some studies. For example, Bailey et al. (2008) estimate a model that assumes that birth rates and death rates are the ultimate drivers of VMT, as opposed to variables that are much more directly related to travel demand, such as total population, lane miles, transit guideway miles, and fuel prices.
- Studies do not produce reliable results. Some of the multiplier studies, such as New York MTA (2009), produce highly variable multiplier estimates depending on the assumptions that researchers make.

Fundamentally, the very concept of a fixed multiplier that does not vary over space and time is questionable. A transit project in an already compact metropolitan area may produce greater indirect benefits than a project in a sprawling area because the compact area encourages walk trips generally, or the reverse could be true because there is so much room for densification in a sprawling area. Land use patterns take a long time to develop, and thereafter are slow to change, so the multiplier effect will likely be greater 10 or 20 years after a transit project is built than it will be either 1 or 5 years after completion. Any measure of transit's indirect effects on travel patterns should take this temporal factor into account.

Transit Impact Area

A transit multiplier applies specifically to an area around a transit station in which the conditions of the built environment and travel choices change after service is initiated. The area may densify, become more diverse in terms of land uses, or become more pedestrian-friendly in terms of street design. The change in the built environment affects walking for purposes other than transit access, and may even affect automobile driving distances, both of which affect VMT independent of transit use. Most planners talk of a half-mile impact or catchment area around rail stations. However, several recent studies have challenged this standard and argued that rail, at least, has effects on land uses and values and travel behavior at a greater distance than previously estimated (Canepa, 2007; Iacono, Krizek, & El-Geneidy, 2008; Ker & Ginn, 2003; O'Sullivan & Morrall, 1996; Petheram, Nelson, Miller, & Ewing, 2013). If people come to a transit station by modes other than walking, the catchment area will expand with the speed of the mode. The catchment area will be larger for bicycling than walking, and larger for feeder bus service than bicycling. Regardless of the mode of rail access, land use patterns in proximity to transit stations and travel choices of residents may change.

One way to know how far transit's influence extends around a transit station is to assess how the market responds to station proximity according to distance. In Salt Lake County (UT), Petheram et al. (2013) find a positive relationship between LRT station proximity and rental apartment building values out to 1.25 miles. Since development density naturally increases with land prices, land uses might be affected by transit out to 1.25 miles. In another study, Canepa (2007) argues that housing and employment density and urban design can push catchment areas to a mile or more. The transit catchment area can be increased by removing physical barriers between land uses and transit stations, especially by providing direct pathways to transit stations.

Our Research Approach

To assess the impact of Portland's Westside LRT line on household VMT, we have gathered and pooled data from two travel surveys in Portland: one for 1994 before the line and then for 2011 well after the line, thereby permitting longitudinal comparisons. These two dates, separated by 17 years, allow us to study the effect of transit investments on VMT in and around transit stations. By studying changes in an otherwise comparable corridor without LRT, we can control for general trends in development and travel on the west side of Portland. With a bit of manipulation, we can also separate direct effects from indirect effects.

Our work is in contrast to the vast majority of studies of travel and the built environment that are cross-sectional in nature. Longitudinal studies that use data for the same places over time to predict behavior are rare because longitudinal data are rare. Yet the approach we take responds to a 2005 National Research Council report calling for studies of so-called natural experiments, changes that occur naturally when some public or private action alters the built environment. "When changes are made to the built environment—whether retrofitting existing environments or constructing new developments or communities—researchers should view such natural experiments as 'demonstration' projects and analyze their impacts on physical activity" (National Research Council Committee on Physical Activity, Land Use, & Institute of Medicine, 2005, p. 12).

We take advantage of the fact that a natural experiment occurs every time a new transit line is built. We expect well-located transit lines will attract new development, changing the built environment of the station areas and thus creating a corresponding change in household travel behavior. Ours is a classic quasi-experimental study design referred to as a pretest–posttest (pre-intervention and post-intervention) design with a comparison group (Shadish, Cook, & Campbell, 2002). By comparing the difference in outcomes between pretest and posttest for the treated group and the comparison group, we can determine whether the treated group has experienced greater changes from pretest to posttest than has the comparison group. If the differences are statistically significant, this is relatively strong evidence of a treatment effect.

We focus on the Westside LRT line (western portion of the Blue Line), the portion that starts almost two miles west of downtown Portland and extends through Beaverton out to Hillsboro. This 15-mile section, with 17 stations, opened in 1998, after the first Household Travel Survey and well before the second. Much of the alignment is through land that was ripe for development or redevelopment. Station areas have had many years to densify and thereby affect travel behavior. This represents our best opportunity for a pre-intervention and post-intervention comparison.

Only the Westside LRT line would be expected to substantially affect land use and travel patterns between the two survey years, 1994 and 2011, and to have effects that are readily isolated methodologically. The Eastside LRT line was completed in 1986, eight years before the 1994 Household Travel Survey, and thus had already had much of its ultimate impact on development patterns by the time of the survey. The Airport LRT Red Line, opened in 2001, mostly travels through land that is industrial (surrounding the airport). Only one station serves a residential neighborhood, which is bounded by highways. The Downtown Streetcar also began service in 2001. Any reasonable buffer around its stations would encompass LRT stations as well, making it difficult to isolate the streetcar's effect on land use. The Interstate LRT Yellow Line, which opened in 2004, may not exemplify the potential of rail to affect development patterns due to its alignment along the interstate. Portland's fifth LRT line, the Green Line connecting downtown Portland to Clackamas County, was opened in 2009, too recently to have had much effect on development patterns in the corridor.

Control Selection

To estimate the impact of the Westside LRT we have to select an appropriate control, what is often referred to as a "counterfactual," in this case comparing a group of people who did not receive the treatment—new light rail services—with those who did (Shadish et al., 2002). Since we cannot actually observe a counterfactual, we select a control group that measures what most likely would have happened in the Westside transit corridor in the absence of LRT. Since the region is constantly growing and suburbanizing, and transportation investments are constantly being made, it would not be reasonable to assume that nothing would have happened even in the absence of the light rail.

In this particular case, we have a good idea what would have happened in the absence of LRT. In the early 1990s, the Portland regional transportation plan featured heavy highway investments on the west side, including a Western Bypass (beltway) and supportive arterial improvements. The now famous land use–transportation–air quality (LUTRAQ) study was undertaken to decide between the plan and an alternative scenario, which featured an LRT line out to Hillsboro and supportive TOD development in the corridor. This was referred to as the LUTRAQ scenario. The study showed that the LUTRAQ scenario would outperform the highway/sprawl scenario with respect to VMT and most other performance indicators. Therefore, the former was selected as the preferred alternative, LRT was built, and the Western Bypass was scrapped. Thus, a reasonable counterfactual for LRT expansion is a highway-oriented alternative.

We considered three highway corridors as potential controls for the Westside LRT corridor. All three lie on the west side of Portland, and extend out from the Portland core. These were selected over east-side corridors both because of their location within the region, and the fact that none of them received an LRT intervention during the period under study. In contrast, any potential east-side corridors lie along or intersect with other LRT lines.

The three highway corridors are shown in Figure 2. One heads to the northwest along the NW Sunset Highway

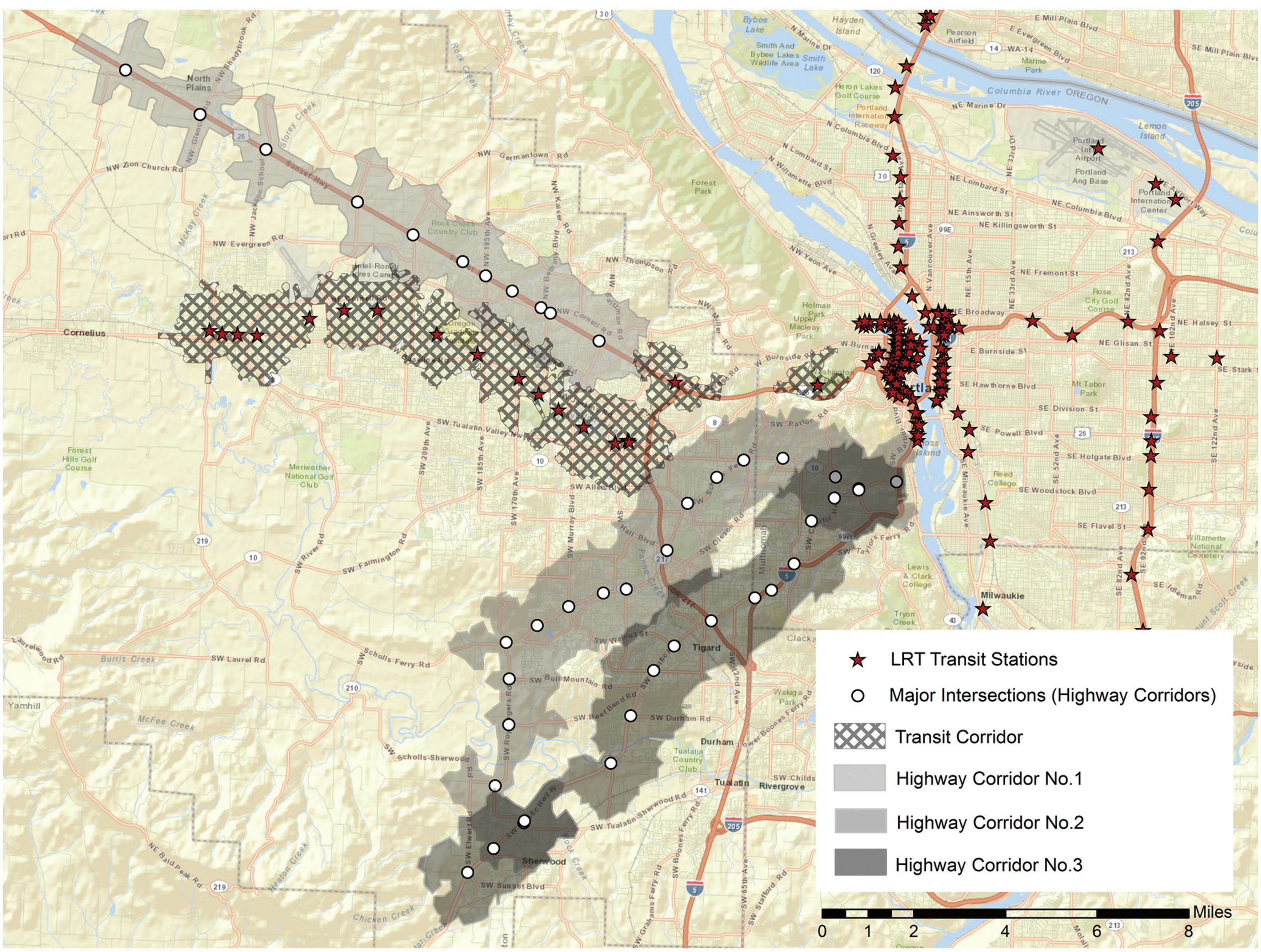

Figure 2. Transit corridor versus three potential highway corridors.

(lightest shading). The second heads to the southwest along State Highway 210 (medium shading). The third heads further south along Interstate 5 and the SW Pacific Highway to Tigard and beyond (darkest shading). The LRT corridor is shown with a crosshatched pattern. As a match with the LRT corridor, we selected the corridor running along the SW Pacific Highway. The corridor is 12.5 miles and has 14 major intersections along it. Of the three potential comparison corridors, this corridor had the most similar sociodemographics to the LRT corridor in the two survey years. In particular, it had comparable household income before the intervention (in 1994) and, importantly, comparable household income after the intervention (in 2011). Hence, we do not have to worry about income confounding the relationship between LRT construction and travel characteristics. With the NW Sunset corridor, household income was significantly higher before and after the intervention. With the State Highway 210 corridor, household income was significantly higher after the intervention.

In a quasi-experimental study, the comparison group should be as similar as possible to the treated group. If the two groups were equivalent, this would be a true experiment, but because they can never be truly equivalent in planning practice, a quasi-experiment is the best we can do. In the next section, we test for rough equivalence of travel and other statistics before the intervention. The existence of big differences before the intervention would create statistical problems, most notably the likelihood of regression to the mean.[1]

Data

This study uses geocoded household travel data to explain household VMT in terms of sociodemographic, built environment, and travel variables. The sample of households varies with the specific test being conducted or model being estimated. The data come from surveys conducted in 1994, four years before the opening of the Westside LRT line, and 2011, 13 years after the opening. The 1994 survey was a two-day travel survey. We selected the first travel day for each household. There is a known tendency of trip reporting to drop off with time in a multi-day survey. The 2011 survey was a one-day survey that covered a larger sample of households.

This study also uses socioeconomic data for surveyed households, built environmental data for buffers around household locations, and transit service data for households and buffer areas. Both travel diary surveys provide X–Y coordinates for households and their trips, which allows travel to be modeled in terms of the precise built environment in which households reside and travel occurs. Purpose, travel mode, travel time, and other variables are available from the survey data set for individual trips. Distance traveled on each trip was either supplied or computed with GIS from the X–Y coordinates. Household size, household income, and other variables were available from the survey data set, which allowed us to control for sociodemographic influences on travel at the household level.

Other data sets have been collected for the same years as the travel surveys to estimate values of many built environmental variables for .25-mile, .5-mile, and 1-mile radius buffers around each household. These include a geocoded parcel land use layer, geocoded street and transit layers, and travel time skims, population, and employment by traffic analysis zone as supplied by the regional metropolitan planning organization, Portland Metro.

We acquired parcel-level assessor data in the survey area from each individual county to estimate the amount and type of each land use within the buffers. We converted parcel features to centroid points, allowing us to join parcel attributes to the buffer polygons. We used roadway centerlines to collect intersection points, counting and summarizing centerline intersections. We collected transit stop geographic locations from all operators serving the travel survey area, merging stops according to bus or rail categories. We joined bus and rail stop locations to buffers for stop counts. We determined population density by weighting census block group population estimates with residential parcel square footage, and then applied population density per square foot to residential parcels intersecting each buffer. We obtained employment data at the traffic zone (TAZ) level from Portland Metro, which we used, along with interzonal travel times, to compute employment accessible within 10-, 20-, and 30-minute auto travel times and within 30-minute transit travel times. We generated employment for individual household buffers by weighting the size of the TAZ in proportion to the buffer and then multiplying by the number of jobs in each intersecting TAZ.

Table 2 shows the variables used in the study. Measures of household size, employment, VMT, and trip frequency refer only to household members who completed travel diaries; we have no data for other household members. We defined and measured all variables consistently for the two survey years and adjusted household income for consumer price inflation. Even adjusting for inflation, incomes rose substantially between 1994 and 2011 across the prosperous Portland region.

Importantly, we have used a 1.25-mile network distance to define the study area around the transit stations on the Westside LRT line and around the intersections on the SW Pacific Highway. This buffer produces an adequate sample of households for statistical purposes, and also squares with the "transit impact area" literature cited here. Surveyed households are represented by dots in Figure 3,

Table 2. Variable definitions.

Variables	Definition	Explanation
Location	Household within 1.25 miles of a Westside LRT station or a SW Pacific Highway intersection	A 1.25-mile buffer was used as the impact area of a LRT station
Household socioeconomic variables		
hhsize	Household size	Only includes household members who completed travel diaries
employed	Employed household members	Only includes household members who completed travel diaries
income	Household income in thousands of 2012 dollars	Income inflated by the personal consumption expenditure price index
vehicles	Household vehicles	Number of cars and other vehicles owned by household
Household built environment variables		
actden	Activity density within the 0.25-mile buffer in thousands of persons per square mile	Population + employment divided by gross land area in square miles
jobpop	Job–population balance within the 0.25-mile buffer	Index ranging from 0, where only jobs or residents are present within 0.25 mile, to 1, where there is 1 job per 5 residents
entropy	Land use mix within the 0.25-mile buffer	Entropy index based on net acreage in different land use categories that ranges from 0, where all developed land is in one use, to 1, where developed land is evenly divided among uses
intden	Intersection density within the 0.25-mile buffer	Number of intersections divided by gross land area in square miles
int4way	Percentage of four-way intersections within the 0.25-mile buffer	Four-way or more intersections divided by total intersections
emp10a	Percentage of regional employment accessible within a 10-minute travel time via auto	Midday travel times
emp20a	Percentage of regional employment accessible within a 20-minute travel time via auto	Midday travel times
emp30a	Percentage of regional employment accessible within a 30-minute travel time via auto	Midday travel times
Household travel variables		
vmt	Average household VMT per day	Adjusted for average vehicle occupancy by household size from 2009 National Household Travel Survey
wtrips	Number of household walk trips	Only includes household members who completed travel diaries
btrips	Number of household bike trips	Only includes household members who completed travel diaries
ttrips	Number of household transit trips	Only includes household members who completed travel diaries
atrips	Number of household auto person trips	Only includes household members who completed travel diaries
trips	Number of household person trips by all modes	Only includes household members who completed travel diaries
adist	Average length of automobile trips	Only includes household members who completed travel diaries
n	Sample size	

with light dots representing households surveyed in 1994 and dark dots representing households surveyed in 2011. By using a larger buffer than the conventional half-mile, we are not suggesting that the effects of LRT on travel and density are uniform within the buffer; we are suggesting, however, that average effects over a larger area can be used to define transit's impacts on VMT.

Statistical Methods

We analyze the data here in two parts. First, we use independent samples difference-of-means tests to see if household travel and other variables differ between the LRT corridor and the comparison corridor, and between the first survey and the second survey. We are looking for gross effects of the new LRT line on household travel and development patterns around the stations. Second, we estimate a household VMT model in terms of household sociodemographic variables, built environment variables for their surroundings, and the variables of greatest interest: household transit trips, household walk trips, and activity density. Once estimated, the model can be used to predict the direct effect of LRT on household VMT through increased transit usage, and the indirect effect of LRT on household VMT through increased walking and activity density around stations.

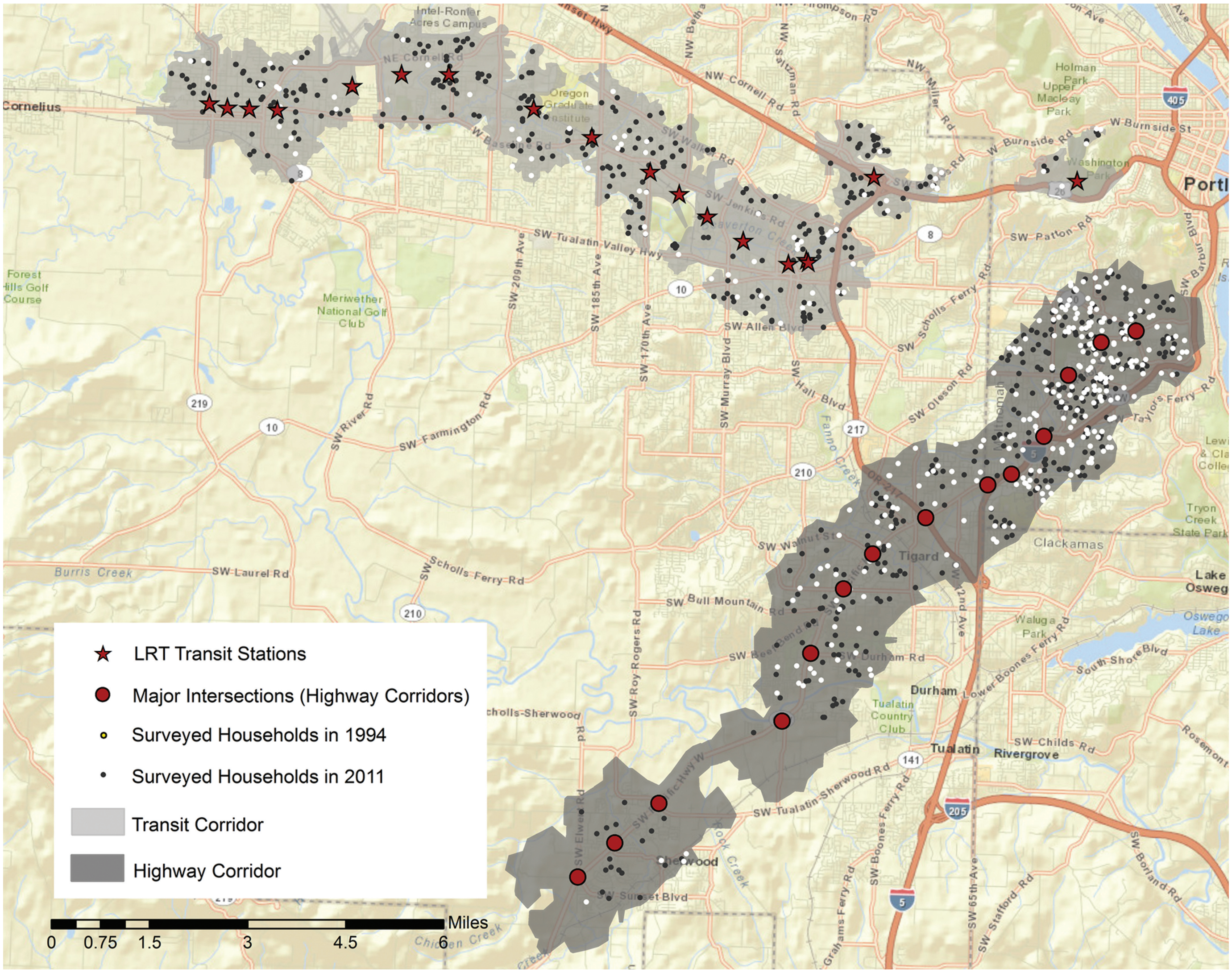

Figure 3. Surveyed households in transit and highway corridors in 1994 and 2011.

Difference-of-Means Tests

We begin with the results of difference-of-means tests. Table 3 permits a pre-intervention comparison of the Westside LRT corridor and the SW Pacific Highway corridor. This may be the most important comparison of all, as large differences would introduce the likelihood of regression to the mean. In 1994, the two corridors were equivalent in almost all respects: There was no significant difference in mean household size, mean number of employees per household, mean income per household, mean activity density, and mean frequencies of walk, bike, auto, and total trip making. Also, most important, there was no significant difference in mean household VMT. Interestingly, transit trip frequency was actually higher in the highway corridor. By this measure, the highway corridor was more urbanized in 1994 than the transit corridor.

As Table 4 shows, by 2011, the LRT corridor had changed with the introduction of LRT, and now differed from the highway corridor in most respects. Real household incomes had risen in both corridors, and were slightly (not significantly) higher in the highway corridor. Activity density, which had been slightly lower in the transit corridor, was now marginally higher. The mean walk and transit trip rates rose in both corridors, but much faster in the transit corridor. Most important for this study, while the mean household VMT rose in both corridors, it rose much faster in the highway corridor. The respective percentage increases were 22% for the transit corridor and 62% for the highway corridor. The rapid rise in household VMT in the highway corridor mirrors the region as a whole, where average VMT per household increased by 49% in the 17 years. Hence, to some degree, the LRT corridor defies the regional trend.

Table 5 shows the final comparison of household data for the transit corridor before and after the Westside LRT line opened. Average household income increased significantly between the years, which partially accounts for the

Table 3. Westside LRT Corridor versus SW Pacific Highway Corridor in 1994.

	LRT	Control	*t* ratio	*p* value
hhsize	2.54	2.16	1.86	.067
employed	1.18	1.24	–0.44	0.66
income (thousands)	62.00	62.81	–0.21	0.84
vehicles	1.72	1.77	–0.39	0.70
actden (thousands)	4.44	4.51	–0.28	0.78
vmt	17.39	18.25	–0.35	0.72
wtrips	0.86	0.83	0.14	0.89
btrips	0.12	0.05	0.77	0.45
ttrips	0.05	0.30	–3.60	<0.001
atrips	6.77	6.59	0.25	0.80
trips	10.74	9.73	1.075	0.28
n (varies but max)	65	237		

Table 5. Westside LRT Corridor in 1994 versus 2011.

	1994	2011	*t* ratio	*p* value
hhsize	2.54	2.12	2.09	0.040
employed	1.18	1.19	–.047	0.96
income (thousands)	62.00	74.30	–3.12	0.002
vehicles	1.72	1.67	0.38	0.71
actden (thousands)	4.44	8.60	–16.81	<0.001
vmt	17.39	21.22	–1.29	0.20
wtrips	0.86	2.16	–4.66	<0.001
btrips	0.12	0.11	0.16	0.88
ttrips	0.046	0.85	–7.14	<0.001
atrips	6.77	6.31	0.52	0.61
trips	10.74	10.80	–.054	0.96
n (varies but max)	65	311		

higher VMT in 2011. Activity density increased by almost 100%, as land near stations was rezoned in many cases for TOD (dense mixed-use development). Walk and transit rates both increased dramatically after LRT (151% and 1,750%, respectively). In absolute terms, the walk rate actually increased more than the transit rate (1.30 vs. 0.80 trips), suggesting the indirect effect of transit investment through increased walking may be as large or larger than the direct effect through increased transit use.

Why the big increase in walking? The most likely explanation is that local governments, Portland Metro (the regional government), TriMet (the transit operator), and even the State of Oregon have been aggressively promoting TOD around transit stations. It is not the transit line itself that leads to increased walking, but rather the TOD, which is attracted to transit station areas, encouraged, and made possible by all levels of government. The Discussion section provides more detail.

Table 4. Westside LRT Corridor versus SW Pacific Highway Corridor in 2011.

	LRT	Control	*t* ratio	*p* value
hhsize	2.12	2.23	–1.11	0.27
employed	1.19	1.42	–3.52	<0.001
income (thousands)	74.30	78.97	–1.25	0.21
vehicles	1.67	1.85	–2.18	0.030
actden (thousands)	8.60	8.53	2.02	0.044
vmt	21.22	29.40	–3.68	<0.001
wtrips	2.16	1.53	2.21	0.018
btrips	0.11	0.24	–1.76	0.079
ttrips	0.85	0.50	2.83	0.005
atrips	6.31	8.09	–3.29	0.001
trips	10.80	10.87	–0.11	0.92
n (varies but max)	311	294		

Generalizing from the tables, household VMT increased in both corridors between 1994 and 2011, but much less so in the Westside LRT corridor than in the highway corridor or the region as a whole. VMT increases across the region are probably related to rising incomes and increasing sprawl (yes, even in Portland). The fact that VMT in the transit corridor did not rise as fast appears to be largely due to mode shifts from the automobile to walking and transit, but many variables were at play. These kinds of comparisons naturally suggest a multivariate analysis, as many variables contribute to household VMT.

Two-Stage Models

To predict the direct and indirect effects of the Westside LRT line on household VMT, we first estimated a two-stage model known in the econometric literature as a "hurdle" model (Greene, 2011). Such models are described and justified in the Technical Appendix. The stage 1 model categorizes households as either generating VMT or not. The stage 2 model estimates the amount of VMT generated by households with any (positive) VMT. We are aware of no previous application of hurdle models to the planning field.

We used Portland data for the entire region in 2011. The model was estimated for 2011 because we want to know how changes in the LRT corridor between 1994 (pre-LRT) and 2011 (post-LRT) likely affected household VMT in 2011. Even when we exclude households with missing values of one or more variables, we still have a sample of 3,665 households across the entire region.

As for independent variables in the two models, we tested variables from Table 2 and chose those with expected signs and conventional significance levels. The significant variables are described in the Technical Appendix. Based on significance levels and effect sizes, we opted for independent variables measured for a quarter-mile around households, the smallest buffer that captured the most localized conditions and still achieved a good model fit.[2]

Impact of Rail Investments on VMT

The best-fit models are shown in the Technical Appendix. The models include most of the so-called D variables from the household travel literature (Ewing & Cervero, 2010; Ewing et al., 2011). The measure of density is activity density. The measure of diversity is land use entropy. The measure of design is the percentage of four-way intersections. The measure of destination accessibility is the percentage of regional employment within 10 minutes by auto, which controls for regional location (as opposed to local conditions). Previous studies have found that regional accessibility is the most important determinant of VMT, more important than the local D variables. The remaining D variables capture household sociodemographics.

The likelihood of a household having any VMT increases with household size and household income and decreases with destination accessibility, entropy, and percentage of four-way intersections. The three variables of ultimate interest are also significant. Households that use transit are less likely to drive. Households that walk are also less likely to drive. Households living at higher densities are less likely to drive, independent of the numbers of transit and walk trips.

For households that drive, household VMT increases with household size, number of employed members, and household income, and decreases with destination accessibility and percentage of four-way intersections. The three variables of ultimate interest are also significant. Households that use transit drive less. Households that walk drive less. Households living at higher densities drive less, independent of the numbers of transit and walk trips.

We next apply these relationships to the "difference in difference" in average transit trip making, walking, and density between the two corridors to estimate how much VMT per capita changed based on direct and indirect effects of LRT. The assumption in this quasi-experimental study is that transit trip making, walking, and density would, in the absence of LRT in the transit corridor, have changed between 1994 and 2011 to the same degree as they changed in the control corridor. This is a standard assumption in pretest–posttest quasi-experimental studies with control groups (Shadish et al., 2002). The cross-sectional VMT model is simply used as a vehicle to implement the quasi-experimental design.

Assuming transit use would have increased by this same amount in the transit corridor as in the highway corridor in the absence of LRT, the net effect of LRT on transit trip making in the LRT corridor (the difference in difference) is 0.60 transit trips per household. Assuming walking would have increased by this same amount in the transit corridor as the highway corridor in the absence of LRT, the net effect of LRT on walk trips in the LRT corridor (the difference in difference) is 0.60 walk trips per household. Finally, assuming activity density in the transit corridor would have increased by this same amount as in the highway corridor in the absence of LRT, the net increase in the activity density (the difference in difference) attributable to LRT is 0.14 thousand persons per square mile, a marginal increase. Both corridors densified substantially over the 17-year period, and much more than expected for the highway corridor.

To determine the direct effect of the LRT line on household VMT, we substitute the net change in the average transit trip rate into the VMT models. A 0.60 increase in the number of transit trips reduces the expected average VMT from 15.44 to 14.97 vehicle miles per household per day, a reduction of 0.47 VMT. A 0.60 increase in the number of walk trips reduces the expected average VMT from 15.44 to 14.72 vehicle miles per household per day, a reduction of 0.72 VMT. A 0.14 thousand persons per square mile increase in activity density reduces the predicted average VMT from 15.44 to 15.18 vehicle miles per household per day, a reduction of 0.26 VMT. When all three effects occur simultaneously, the models tell us that household VMT would drop from 15.44 to 14.01.

The transit multiplier is just the total reduction in household VMT when all three effects are considered (1.43) divided by the reduction in household VMT due to the direct effect of transit trips alone (0.47), or 3.04. That is, the total effect of transit on VMT due to compact land uses near stations and increased walking is three times that of the direct effect due to ridership increases.

Policy Implications

A growing body of research suggests that transit investments have both direct and indirect effects on VMT, that the indirect effect through TOD around stations may be greater than the direct effect through transit ridership alone, and that the so-called transit multiplier (total effect divided by direct effect) ranges from 1.29 to 9.0. In this study, we assess the direct and indirect effects on car use (as measured by household VMT) of the Portland Westside Max LRT extension over a 17-year period. Unlike other studies, we use longitudinal data, which are far superior to cross-sectional data, to estimate effects of discrete changes in the built environment, and we compare a treated transit corridor with a highway corridor that serves as a control.

We find that the corridor in which the Westside LRT line was built became denser, generated more household walk and transit trips, and experienced a slower rise in VMT per household than did the SW Pacific Highway Corridor, which became our control corridor for purposes of comparison. Local governments, Portland Metro (the regional government), TriMet (the transit operator), and the even the state government have all taken steps to encourage TOD around transit stops; apparently, it has worked. The cities of Hillsboro and Beaverton have made major modifications to zoning around stops to encourage TOD, and have also designated urban renewal areas and made public investments in station areas using tax increment financing. Finally, they have added amenities close to stations such as a main street theater, performing arts center, and civic center, with a large plaza for civic events. Portland Metro has launched a major educational campaign to promote TOD called "Get Centered," channeled a disproportionate share of transportation dollars into centers and corridors, and purchased easements in TODs to encourage denser development. TriMet, the transit operator, has developed its parking lots and other excess lands in active uses at stations themselves. Also, the State of Oregon has enacted tax abatements, subject to local approval, for development in centers.

Naturally, this analysis has its limitations, suggesting several possible future investigations. First, our household sample sizes are small, particularly for the transit corridor in 1994, which had only 65 surveyed households. The difference-of-means tests are affected by small sample sizes, and our confidence in their results is thereby limited. Second, we have no ability to account for micro-design characteristics of the built environment that may render one environment more pedestrian-friendly than another, and account for differences in walk and transit usage. That is to say, much of what makes an area pleasant for pedestrians (Ewing & Clemente, 2013) is too fine-grained to be captured by our metrics. Third, we have no ability to account for residential self-selection; that is, the tendency of those who want to walk or use transit selecting to live in TODs near stations. While residents of the two corridors are matched for household size and income, they may have entirely different attitudes toward walking and transit use. Those who have selected to live near transit stations may be more inclined to use transit and walk, regardless of where they live; we just cannot measure such differences without attitudinal data. It may be this phenomenon rather than the environment of transit station areas that accounts for different rates of walking and transit use between the two corridors.

As debates about air quality, energy, and climate policy have increased, more attention has been paid to the roles of urban form and transit infrastructure in addressing these policy challenges. The vigor that has accompanied research in the area, however, has sometimes given rise to warnings against overexuberance. A special Transportation Research Board panel recently acknowledged that land development patterns likely have an influence on travel, but signaled that it did not have as much "verifiable scientific evidence" as it would like to have to support its conclusions (American Public Transportation Association, 2009, p. 131). Our study contributes verifiable scientific evidence, based on a strong quasi-experimental design, on the size of transit's land use multiplier when complemented by supportive public policies and investments. Future studies can build on these findings.

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Notes

1. *Regression to the mean* is the technical term for things evening out. Specifically, it refers to the tendency of a random variable, which is well above or below the mean value in one period, to return to a "normal" value closer to the mean in the next period. If the treated group had much higher or lower VMT than the comparison group before the treatment, for example, we would expect it to even out after the treatment regardless of the treatment itself.

2. We also prefer the smaller buffers because larger buffers would extend far beyond the 1.25-mile catchment area around the transit stations (2.25 miles for households at the border of the catchment area).

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Technical Appendix

Vehicle miles traveled (VMT) per household has two characteristics that complicate modeling. First, it is nonnormally distributed because it is highly skewed to the left. The solution to this problem is to take the natural logarithm of VMT, which becomes our dependent variable (lnvmt). Second, it has a large number of zero values for households that generate no VMT. These households use only alternative modes such as transit or walking. A total of 9% of households in the sample fall into this category. When VMT is log transformed, these households have undefined values of the dependent variable.

In the planning literature, the problem of zero values is often handled by adding 1.0 to the value of a dependent variable and then log transforming the variable; the 1 then becomes a zero when transformed. This is not econometrically correct, however, since households with zero values may be qualitatively different than those with positive values: "In some settings, the zero outcome of the data-generating process is qualitatively different from the positive ones. The zero or nonzero values of the outcome is the result of a separate decision whether or not to 'participate' in the activity. On deciding to participate, the individual decides separately how much to, that is, how intensively [to participate]" (Greene, 2011, p. 824).

The proper solution to the problem of excess zero values (what is referred to in the econometric literature as "zero inflation") is to estimate two-stage "hurdle" models (Greene, 2011). The stage 1 model categorizes households as either generating VMT or not. The stage 2 model estimates the amount of VMT generated by households with any (positive) VMT. We are aware of no previous application of hurdle models to the planning field.

Both models include the natural log of household size (lnhhsize), the natural log of household income (lnincome), the percentage of regional employment accessible within 10 minutes by automobile (emp10a), the percentage of four-way intersections within 0.25 mile of the household (int4wy), activity density within 0.25 mile of the household in thousands (actden), the number of walk trips made by the household (wtrips), and the number of transit trips made by the household (ttrips). The number of employed members of the household (employed) is significant only in the logarithm of VMT model, while land use entropy within 0.25 mile of the household (entropy) is significant only in the any VMT model. We took the natural log of household size and household income to account for nonlinear relationships to VMT.

For the built environmental variables in our model, we had three buffer widths to choose from (0.25, 0.5, and 1 mile). The buffers characterize the built environments around household addresses, either narrow or wide. It is not clear what built environment will have the greatest effect on household VMT, the environment within an easy walking distance (0.25 mile) or the environment within an easy driving distance (1 mile). Based on significance levels and effect sizes, we opted for the smallest buffer to capture the most localized conditions and still achieve a good model fit.

Best-Fit Models

The best-fit models are shown in Tables A-1 and A-2. In the model for any VMT, sociodemographic and built environmental control variables proved highly significant, and the model itself has a reasonably high pseudo-R^2 (see Table A-1). The number of transit trips made by the household has the expected negative sign and is significant at the 0.004 level. The coefficient value, –0.147, means that a one-unit increase in transit trips results in a 14% decrease in the odds of a household having any VMT (not the probability, but instead the odds). The number of walk trips made by the household has the expected negative sign and is significant at the 0.001 level or beyond. The coefficient value, –0.328, means that a one-unit increase in transit trips results in a 28% decrease in the odds of a household having any VMT. Activity density also has a negative sign and is significant at the 0.023 level. The coefficient value, –0.354, means that a one-unit increase in activity density (expressed in thousands) results in a 30% decrease in the odds of any VMT.

Table A-1. Logistic regression model of log odds of any household VMT in 2011.

	Coefficient	Standard error	*t* ratio	*p* value
constant	4.469	1.303	11.77	0.001
lnhhsize	2.761	0.210	172.78	<0.001
lnincome	0.413	0.085	23.59	<0.001
emp10a	–0.022	0.014	2.55	0.110
entropy	–0.793	0.308	6.63	0.010
int4way	–0.005	0.003	2.98	0.084
actden (thousands)	–0.354	0.156	5.17	0.023
wtrips	–0.328	0.028	140.72	<0.001
ttrips	–0.147	0.052	8.086	0.004

Notes: Outcome variable is anyvmt. pseudo-R^2 = 0.48. –2 log-likelihood ratio: 1,525.

Table A-2. Linear regression model of natural log of household VMT in 2011 (for households with any VMT).

	Coefficient	Standard error	*t* ratio	*p* value
constant	2.919	0.165	17.71	<0.001
lnhhsize	0.677	0.034	20.06	<0.001
employed	0.118	0.022	5.36	<0.001
lnincome	0.145	0.023	6.32	<0.001
emp10a	–0.011	0.003	–3.36	<0.001
int4way	–0.002	0.001	–2.73	<0.006
actden (thousands)	–0.111	0.018	–6.17	<0.001
wtrips	–0.067	0.007	–9.17	0.006
ttrips	–0.047	0.017	–2.74	<0.001

Notes: N = 3,665. R^2 = 0.262.

Likewise, in the logarithm of the VMT model, sociodemographic and built environmental control variables proved highly significant, and the model itself has a reasonable R^2 for a model based on disaggregate data (see Table A-2). The number of transit trips made by the household has the expected negative sign and is significant at the 0.006 level. The coefficient value, –0.047, means that a one-unit increase in transit trips results in a –0.047% decrease in VMT per household. The number of walk trips made by the household has the expected negative sign and is significant at the 0.001 level or beyond. The coefficient value, –0.067, means that a one-unit increase in walk trips results in a –0.067% decrease in VMT per household. Activity density also has a negative sign and is significant at the 0.001 level or beyond. The coefficient value, –0.111, means that a one-unit increase in activity density (expressed in thousands) results in a –0.111% decrease in VMT per household.

The VMT models just estimated are cross-sectional and involve the entire 2011 sample of households in the Portland region. We next apply these relationships to the "difference in difference" in average transit trip making, walking, and density between the two corridors to estimate how much VMT per capita changed based on direct and indirect effects of LRT. Consistent with our quasi-experimental methodology, we assume a counterfactual that in the absence of LRT, transit use, walking, and activity density in the transit corridor would have changed to just the same extent as in the highway corridor. The cross-sectional VMT model is simply used as a vehicle to implement the quasi-experimental design.

Between 1994 and 2011, the average number of transit trips per household in the LRT corridor rose from 0.05 to 0.85, an increase of 0.80 daily transit trips. During the same period, due to expanded transit service regionally, the average number of transit trips per household in the highway corridor rose from 0.30 to 0.50, an increase of 0.20 transit trips. Assuming transit use would have increased by this same amount in the absence of LRT, the net effect of LRT on transit trip making in the LRT corridor (the difference in difference) is 0.80 minus 0.20, or 0.60 transit trips per household.

Likewise, between 1994 and 2011, the average number of walk trips per household in the LRT corridor rose from 0.86 to 2.16, an increase of 1.30 daily walk trips. During the same period, due to general urbanization in the region, the average number of walk trips per household in the highway corridor rose from 0.83 to 1.53, an increase of 0.70 walk trips. Assuming walking would have increased by this same amount in the absence of LRT, the net effect of LRT on walk trips in the LRT corridor (the difference in difference) is 1.30 minus 0.70, or 0.60 walk trips per household.

Finally, between 1994 and 2011, the average activity density in the LRT corridor rose from 4.44 to 8.60 persons per square mile, expressed in thousands, for an increase of 4.16 persons per square mile, again in thousands. During the same period, due to general urbanization on Portland's west side, the average activity density in the highway corridor rose from 4.51 to 8.53 persons per square mile (in thousands), for an increase of 4.02 thousand persons per square mile. Assuming activity density in the transit corridor would have increased by this same amount in the absence of LRT, the net increase in the activity density (the difference in difference) attributable to LRT is 4.16 minus 4.02, or 0.14 thousand persons per square mile, a marginal increase. Both corridors densified substantially over the 17-year period, much more than expected for the highway corridor.

We next substitute the net change in the average transit trip rate into the VMT models to determine the direct effect of the LRT line on VMT. The logistic equation in Table A-1 allows us to compute the odds of any VMT by exponentiating the log odds, and then computing the probability of any VMT with the formula for the probability in terms of the odds.

$$\textit{odds of any VMT} = \exp(\textit{log odds any VMT})$$
$$\textit{probability of any VMT} = \textit{odds of any VMT} / (1 + \textit{odds of any VMT})$$

From the semi-log equation in Table A-2, we next compute the expected VMT for households with any VMT, again, by exponentiating:

$$\textit{VMT (for households with VMT)} = \exp(\textit{log of VMT})$$

The expected VMT for all households is just the product of the two results.

Because one equation is logistic and the other is semi-log, the effect of an increase in transit trips on household VMT depends on other variables in the VMT model. We substitute the average values of all other variables for the households in the LRT corridor into the two equations to see what the net effect on household VMT will be. Average variable values are listed in Table A-3. A 0.60 increase in the number of transit trips reduces the expected average VMT from 15.4 to 15.0 vehicle miles per household per day, a reduction of 0.4 VMT. A 0.60 increase in the number of walk trips reduces the expected average VMT from 15.4 to 14.7 vehicle miles per household per day, a reduction of 0.7 VMT. A 0.14 thousand increase in activity density reduces the predicted average VMT from 15.4 to 15.2 vehicle miles per household per day, a reduction of 0.2 VMT.

Propensity Score Matching

One of the reviewers of this study advocated the use of propensity score matching in lieu of the study design we have chosen. This is the approach taken in two similar studies (Cao & Schoner, 2014; Cao, Xu, & Fan, 2010). Propensity score matching is a legitimate alternative to the quasi-experimental approach we have taken (pretest–posttest design with a control group). It is just another way of creating a counterfactual. It might be preferable if we were dealing only with cross-sectional data for 2011.

Table A-3. Descriptive statistics for households in the transit corridor.

	n	Mean	Standard deviation
lnvmt	217	2.67	0.87
lnhhsize	237	0.63	0.53
employed	237	1.24	0.84
lnincome	186	4.02	0.57
emp10a	237	12.20	3.89
entropy	236	0.34	0.26
int4way	237	31.94	20.47
actden (thousands)	237	4.51	1.15
wtrips	237	0.827	1.78
ttrips	237	0.295	0.79

In propensity score matching, we would have modeled the probability of a household being in the transit corridor using as many independent variables as are available to us. The resulting logistic equations would have been used to compute propensity scores for all households in the region, and then households in the transit corridor would have been matched to one or more households outside the transit corridor based on similar propensity scores. "The goal is to include all variables that play a role in the selection process (including interactions and other nonlinear terms) and that are presumptively related to [the] outcome….The logistic regression reduces each participant's set of covariates to a single propensity score, thus making it feasible to match or stratify on what are essentially multiple variables simultaneously" (Shadish, Cook, & Campbell, 2002, p. 162).

The most common matching approach, known as nearest neighbor matching, would have matched each household in the transit corridor to the household outside with the most similar propensity score. As advocated by the reviewer, this would have been accomplished first for 1994 and then for 2011, in two cross-sections, expecting no VMT difference in 1994 and some difference in 2011.

The main drawback of this technique is that it is aspatial. While we would have matched households in the transit corridor to households outside, the matched households could have been anywhere within the greater Portland region, or anywhere on the west side of Portland if so limited, and would not necessarily have been in similar locations before and after treatment. Instead, we chose to match households in the transit corridor to households in an otherwise comparable highway corridor.

In addition, the validity of propensity score matching relies on the untestable assumption that unobserved characteristics do not influence treatment participation. Careful substantive justification of this assumption is warranted, and to the degree that this assumption is not met, the estimates from this method can be invalid (Morgan & Winship, 2007). Data are required on a substantial set of untreated individuals for common support to be met. Even when common support is relatively good, dropping treatment cases with very high propensities is often necessary (Khandker, Koolwal, & Samad, 2010). This can bias the estimate of treatment effect. For this reason, propensity score matching might not be the best choice if the treatment effect on the treated is the primary aim of the research question (Stevenson, 2011).

Both of our corridors are on the west side of Portland, running from downtown Portland out to suburban communities. Both are major transportation corridors, one with a transit orientation and the other with a highway orientation. The highway corridor was carefully chosen to be as comparable as possible with the transit corridor in the before period. Unlike other major highway corridors in the greater Portland region, which now nearly all have fixed guideway transit, the chosen highway corridor does not have fixed guideway transit in the before or after period. Given careful matching in the pretest period, it was quite reasonable to expect them to be comparable in the after period, but for the addition of a LRT "treatment."

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